



## MORTAR QUALITY ASSURANCE: A REVIEW OF NORTH AMERICAN PRACTICES

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### ABSTRACT

Mortar, a key component of masonry construction, is typically produced on site per prequalified volume-based proportions, unlike most other building materials. With the advent of engineered masonry construction, specifiers and code authorities have employed various quality control tests to verify the acceptability of site-mixed mortar. Generally, those methods have consisted of selected procedures from ASTM C780, Preconstruction and Construction Evaluation of Field-Mixed Mortars, sometimes modified by a specific code or specification. This paper reviews methods and practices used in the U. S. and Canada, examines reported data, and discusses the advantages and limitations of each. The paper also presents new information on the aggregate ratio test method outlined in Annex 4 of ASTM C 780, including ruggedness and sensitivity data.

**KEYWORDS:** mortar aggregate ratio, field testing, QA

### INTRODUCTION

Assessing mortar quality is a necessary element of masonry construction. The question arises, though, as to what is the best way of verifying the quality of mortar. Results of some test methods (on a single mortar) vary greatly from operator to operator or test to test, even when performed by qualified technicians according to standard test methods. Some tests take too long to give results, which may be available only after the construction work is completed, well past the time window for implementing cost-effective corrective action. Some tests can be performed in a short amount of time, and provide reproducible results, but do not give an indication of mortar quality.

Experience in North America indicates that mortars that meet requirements of ASTM C 270, Specification for Mortar for Unit Masonry [1], or CSA A179, Mortar and Grout for Unit Masonry [2], generally perform as intended. ASTM C 270 and CSA A179 provide that mortar mixtures can be established by either proportion specifications or property specifications. However, for site-mixed mortars, both procedures require that the mason contractor mix mortar materials at the construction site to pre-established volume-based proportions. Verification that

mortar materials meet specification requirements may require laboratory testing. Thus, the focus of a project quality assurance program for masonry mortar should be to determine that site batching and mixing procedures yield pre-established proportions. ASTM C 780, Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry [3], includes methods that can be used for quality control of site-prepared mortar.

This paper will:

- describe field test methods commonly used in North America
- look at past studies of test procedures and quality assurance methods
- present recent research on the mortar aggregate ratio test
- provide a discussion and comparison of the test methods.

## **FIELD TEST PROCEDURES**

Visual inspection is not a test method, but it is an effective tool for ensuring the quality of site mixed mortar. It includes observing and recording mortar batching and mixing procedures, and looking at the mixed mortar. ASTM C 1586, Guide for Quality Assurance of Mortars [4] recommends that inspection or testing, or both, be used to assure proper proportioning of mortar materials at the construction site.

When mortar testing is desired during construction, ASTM C 780 and its annexes provide standard procedures for qualified technicians to use in sampling and testing fresh mortar. Annexes, like the standard, are written in mandatory language. Those procedures are:

Annex 1: Consistency by Cone Penetration Test Method

Annex 2: Consistency Retention of Mortars for Unit Masonry

Annex 3: Initial Consistency and Consistency Retention or Board Life of Masonry Mortars Using a Modified Concrete Penetrometer

Annex 4: Mortar Aggregate Ratio Test Method

Annex 5: Mortar Water Content Test Method

Annex 6: Mortar Air Content Test Method

Annex 7: Compressive Strength of Molded Masonry Mortar Cylinders and Cubes

Annex 8: Splitting Tensile Strength of Molded Masonry Mortar Cylinders

CSA A179 is the counterpart to ASTM C 270 for mortar specification for mortar in Canada. Section 8 of the standard covers 4 tests for mortar and grout, although section 8.3 deals only with (slump of) grout, which is not part of the scope of the current paper:

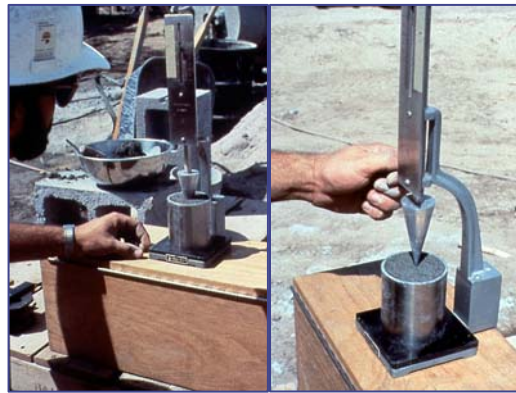
Section 8.2: Determining the sand/cementitious material ratio for mortar

Section 8.4: Determining the compressive strength of mortar and grout

Though there are some differences, Section 8.2 of A179 is similar to Annex 4 of C 780 and Section 8.4 of A179 includes provisions determining compressive strength of field sampled mortar specimens similar to protocol of Annex 7 C 780.

### **ANNEX 1: CONSISTENCY BY CONE PENETRATION TEST METHOD**

This test involves filling a unit measure with fresh mortar, then allowing a modified aluminum cone from the Vicat apparatus to drop from a controlled height into the mortar. The penetration distance is measured in millimetres and gives an indication of the consistency of mortar. Test equipment is transportable, though a level and stable area is needed to run the test. The purpose of this test is to measure mortar consistency. Results are intended to provide a better understanding of the other tests. This test is not to be used for control of water content of mortar. As indicated in ASTM C 270 and numerous other sources, mortar should be mixed with the maximum amount of water that is consistent with workability requirements to optimize its performance. The mason is the best judge of optimum consistency.



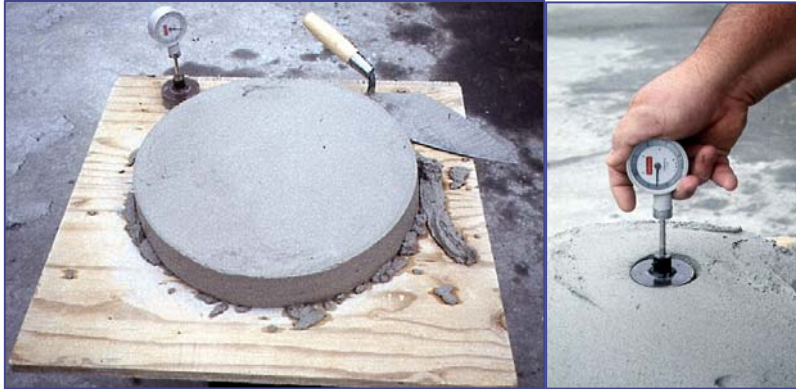
**Figure 1 – Cone Penetration Test Method**

### **ANNEX 2: CONSISTENCY RETENTION OF MORTARS FOR UNIT MASONRY**

Like the previous method, this test looks at penetration of a cone into mortar, but extends the time intervals between repeated tests to (generally) 15 minutes. As before, penetration into the cup of mortar is measured in millimetres, both before and after sitting for 15 minutes. But this does not necessarily tell anything about the quality of mortar in the wall as built. The main purpose of this test is to tell how long a mortar retains a certain degree of plasticity and to identify early-age setting and stiffening characteristics.

### **ANNEX 3: INITIAL CONSISTENCY AND CONSISTENCY RETENTION OR BOARD LIFE OF MASONRY MORTARS USING A MODIFIED CONCRETE PENETROMETER**

This method allows determination of initial consistency and board life by measuring the pressure [in MPa (psi)] required for a 25.4 mm (1 in.) penetration of a disk of a given size and weight into an unhardened mortar sample. Over time, greater pressures are required to penetrate the sample. This test gives an idea of the board life of a mortar, or how long mortar can remain workable. The purpose of this test is to determine stiffening characteristics of a mortar. As a preconstruction test, this can provide information about the length of time mortar can remain at various temperature/humidity conditions before stiffening requires the addition of water and remixing. It is similar to the consistency retention by cone penetration, but sample size and sample conditioning more closely approximate field conditions.



**Figure 2 – Concrete Penetrometer**

#### **ANNEX 4: MORTAR AGGREGATE RATIO TEST METHOD**

This allows the determination of relative proportions of cementitious material to aggregate when used in conjunction with the water content test. Mortar and sand samples taken from field mixed mortar are wet sieved to separate cementitious materials from the aggregate. It is not possible to separate individual cementitious materials when more than one is used. For preblended mortar, the manufacturer must provide a sand sample to allow for calculation of the correction factor. It can be used for quality control of mortar and ASTM C 1586 recommends that this method be used if testing is required to assure mortar proportioning.

#### **ANNEX 5: MORTAR WATER CONTENT TEST METHOD**

This test method determines the water content of mortars. This value allows the calculation of free water in the mortar so that mortar aggregate ratio can be calculated. On its own, water content has little application to determining the quality of masonry mortar because water is field adjusted to meet the needs of the mason during construction.

#### **ANNEX 6: MORTAR AIR CONTENT TEST METHOD**

This test method determines the air content of fresh mortars. A sample is placed into an air meter base which is then tested by either the pressure meter method or the volumetric method. It should be noted that air content of fresh mortar determined according to ASTM C 780 will differ from air content of mortar proportioned, mixed, and tested in accordance with ASTM C 270. Therefore, unless expected values have been established for field proportioned and mixed mortars in preconstruction testing, test results of site mixed mortar will be of little use for quality assurance.

#### **ANNEX 7: COMPRESSIVE STRENGTH OF MOLDED MASONRY MORTAR CYLINDERS AND CUBES**

Mortar types are based on strength under the property specifications, but strength is to be determined on laboratory mixed mortars tested in accordance with ASTM C 270, not C 780. The test procedure of C 780 cannot be used to determine compliance with ASTM C 270 property requirement. If it is used during construction, preconstruction testing that approximates field proportioning and mixing procedures is required to establish expected values. In lieu of preconstruction testing, CSA A179 sets reduced strength requirements at approximately 2/3 of the laboratory specified compressive strength. However, there are many parameters that affect

the compressive strength value obtained on site-sampled mortar. These include water content, ambient temperature, fabrication, and handling and curing of specimens—parameters that influence results but are not indicative of mortar proportions or quality. Furthermore, the test specimens must cure and then be tested at a certain age—usually 7 or 28 days—so results come only after the wall has been built, too late to take corrective action for batching or mixing mortar. Therefore, compressive strength is not a very effective tool for on-site quality control of mortar, nor does it provide meaningful information for quality assurance of mortar.

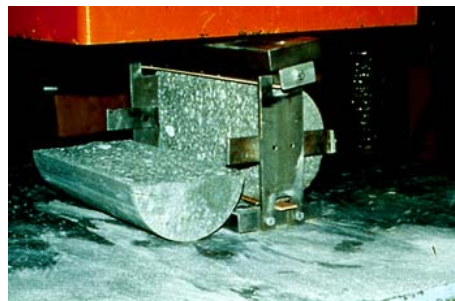
Figure 3 shows 50 mm (2 in. cubes) being fabricated and tested in compression. C 780 requires 3 test specimens for each age. CSA A179 stipulates no fewer than 6 cube specimens for testing mortar. Test age is 7 or 28 days old, but shall be 28 days if not specified.



**Figure 3 – Compressive Strength of Molded Cubes**

#### **ANNEX 8: SPLITTING TENSILE STRENGTH OF MOLDED MASONRY MORTAR CYLINDERS**

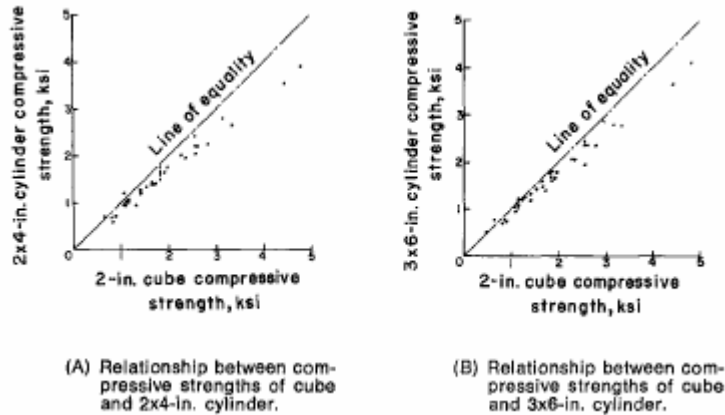
The splitting tensile strength of cylinders can be measured indirectly—using compression. By placing a cylinder lengthwise in a compression test apparatus and loading it along a line, the sample is subjected to a force that simulates pulling it apart. It is a simpler test set-up than would be required to place a specimen in direct tension. Measured strength is dependent upon the mortar water content at the time of set, along with other factors, and reflects the general strength attainable by the mortar in the masonry. The equipment is not portable and specimens require a special mounting assembly. Even more important, there is a wide range of variability in results because the test is sensitive. Slight changes in the specimen shape lead to large differences in measured values. Specimens have to be cured for many days before they can be tested. There are no accepted criteria for interpreting the results of splitting tensile strength of masonry mortar. Huizer et al [5] noted in 1974 that: “Serious doubt exists as to the merit of including this test in the specified site control tests, particularly if well constructed steel molds are not employed.”



**Figure 4 – Splitting Tensile Strength of Cylinders**

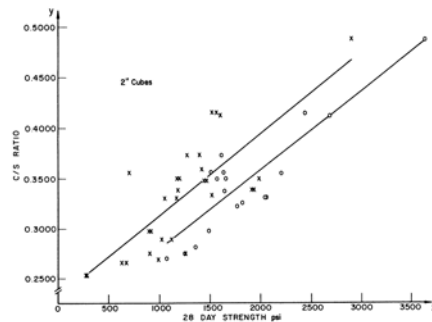
## PAST STUDIES OF TEST PROCEDURES AND QUALITY ASSURANCE

Isberner [6] observed that compressive strength of mortar is affected by specimen size and method of test. Figure 5 shows the effect of sample size on strength. Two cylinder sizes tested (75 x 150 mm and 50 x 100 mm (3 x 6 in. and 2 x 4 in.)) show that both sizes of cylinders possess approximately 15% lower compressive strength than cubes of the same mortar.



**Figure 5 – Compressive Strength of Molded Cubes versus Cylinders**

A direct comparison of mortar aggregate ratio vs. compressive strength is informative. Huizer et al [5] have shown a good linear correlation between mortar aggregate ratio (or cement to sand ratio as they called it, C/S) and laboratory compressive strength (of 50 mm or 2 in. cubes) as shown in Figure 6. Note that C 270 mortars must have between 2-1/4 to 3-1/2 parts of sand per cementitious material, which is equivalent to C/S of 0.29 to 0.44.



**Figure 6 – Linear Regression of 28-day Cube Compressive Strength and Cementitious Material/Sand Ratio [5]**

Good correlation between these parameters indicates that the mortar aggregate ratio has physical meaning and that the test is reproducible. Unlike compressive strength testing, however, results are available early enough to take corrective action if and when that is needed.

## RECENT WORK ON MORTAR AGGREGATE RATIO TEST

Mortar aggregate ratio ruggedness testing by NCMA [7] showed that this test could be improved by clarifying instructions in the ASTM method. Details of the test are described here. A sample



each of wet mortar and one of sand are taken. Samples of mortar are placed into two jars of isopropyl or methyl alcohol. (Alcohol stops the cement hydration.) Sand is placed into a different jar or a plastic bag. The mortar jars are agitated to mix the alcohol throughout the sample, breaking up the cement and sand. For mortar jar number 1, the alcohol is burned off in the lab and the remaining material is oven dried to determine the water content. For mortar jar number 2 and jar number 3 with sand, samples are wet sieved.

For the mortar sample, finer materials are assumed to represent the cementitious materials. The sample is weighed in various conditions: wet, oven dried, and after removal of alcohol. The sand sample allows for a correction of fine particles. The mortar aggregate ratio can then be calculated and represents a simple ratio of sand to cement, such as 3:1.



**Figure 7 – Mortar Aggregate Ratio Test Samples and Wet Sieving**

Recommendations for improving the method given in Table 1 are clarifications of procedures already outlined in ASTM C 780, Annex 4. Results were most affected by testing time, sample size, and agitation. Testing time worked best when the sample was tested within 4 hours of being taken; the smaller sample size of 500 g provided more accurate results than did the larger sample of 700 g; and the importance of agitating the sample in the jar of alcohol was confirmed.

**Table 1 – Suggested Modifications to Improve ASTM C 780  
Mortar Aggregate Ratio Results**

<b>ASTM C 780 Section</b>	<b>Test condition</b>	<b>Current ASTM C 780 Language</b>	<b>Suggested Change</b>
A4.3.2	Board life	None	Add requirement to sample fresh mortar
A4.3.2	Mortar sample size	Sample size 500 g to 700 g	Stipulate 500 g sample
No section	Testing time	None	Conduct testing within 24 hours of sampling mortar

Tests conducted on a student housing project at the University of Florida in Gainesville provided real-world data for analysis. This was a Type S mortar with a mortar aggregate ratio of 3:1. Samples were collected at the job site and data generated by one lab over 11 months. Mortar batching personnel did not know when testing would be performed.

Twenty-six mortar aggregate test results and twenty-one compressive strength results are available and shown in Table 2. The mortar aggregate ratio scatter is shown in Figure 8 using all twenty-six points. Each data point shown on the x-axis represents a particular day the mortar aggregate ratio was determined for field mortar. The average of all mortar aggregate ratio tests is 2.93 with a coefficient of variation of 9.0%. The variation of mortar aggregate ratio results includes both testing and site-batching variability. Additional work is planned to develop precision and bias information for the mortar aggregate ratio test, which is needed to determine how much of the measured variation is due to the test method and how much is due to differences in mortar proportions.

**Table 2 – University of Florida Project Mortar C 780  
Mortar Aggregate Ratio Tests and Compressive Strength Tests**

<b>Sample Number</b>	<b>Mortar Aggregate Ratio</b>	<b>Average Compressive Strength 28-day MPa (psi)</b>	<b>Sample Number</b>	<b>Mortar Aggregate Ratio</b>	<b>Average Compressive Strength 28-day MPa (psi)</b>
1	2.96	-	14	2.99	16.86(2445)
2	2.82	-	15	3.17	15.65(2270)
3	2.62	-	16	2.93	17.34(2515)
4	2.79	-	17	2.82	17.1(2480)
5	3.20	15.75(2285)	18	2.82	17.06(2475)
6	2.81	17.44(2530)	19	2.83	14.86(2155)
7	3.09	16.72(2425)	20	2.79	18.06(2620)
8	3.08	-	21	3.04	17.82(2585)
9	3.24	14.89(2160)	22	2.68	21.51(3120)
10	2.75	15.89(2305)	23	2.36	22.61(3280)
11	3.11	15.89(2305)	24	2.32	21.79(3160)
12	3.12	15.38(2230)	25	3.09	18.31(2655)
13	3.30	15.89(2305)	26	3.40	14.89(2160)

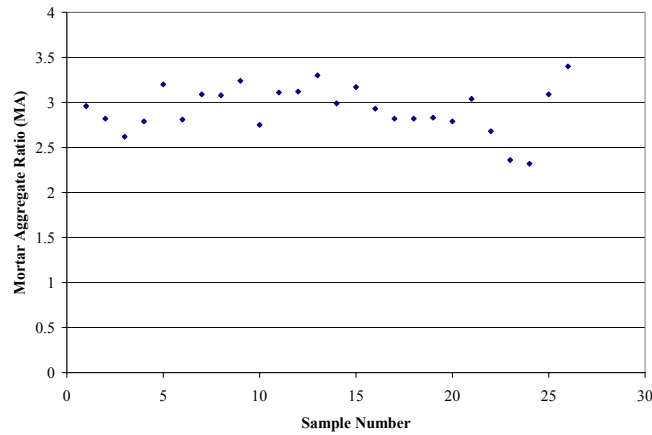
For comparison, Huizer et al [5] reported an average mortar aggregate ratio of 3.08 with a coefficient of variation of 16% for field tests. They recorded that, while measuring boxes were used at the start of the project, the shovel was the only measure used for proportioning as the project progressed. On the University of Florida project, the mixer operator used a measuring box to calibrate and periodically check shovel count. The target mix design was three parts sand to one part cement by volume and it is reasonable to assume that the knowledge that tests were frequently being conducted would have encouraged some additional care in batching procedures.

Using only the University of Florida data for which both mortar aggregate ratio and compressive strength are available, the average mortar aggregate ratio is 2.95 with a coefficient of variation of

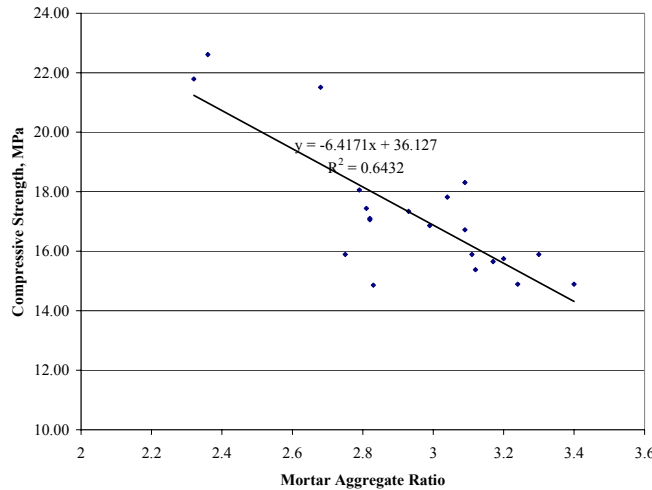


9.5%. The average 28-day compressive strength of the mortar is 17.2 MPa (2498 psi) with a coefficient of variation of 13.0%. The larger coefficient of variation for compressive strength (13%) than for mortar aggregate ratio (9.5%) indicates that compressive strength test results are more variable than mortar aggregate ratio test results. This is consistent with the previous observation that compressive strength values for field sampled mortar are dependent on a number of testing and specimen preparation parameters in addition to mortar proportions. For comparison, Huizer et al [5] reported an average 28-day compressive strength of 8.7 MPa (1255 psi) with a coefficient of variation of 42% for all field tests.

Figure 9 shows the correlation to compressive strength for the same twenty-one samples. There is an inverse correlation between strength and mortar aggregate ratio; as mortar aggregate ratio increases, strength decreases. The physical interpretation is that less cement per volume of sand results in lower strength.



**Figure 8 – Mortar Aggregate Ratio Test Results**



**Figure 9 – Mortar Aggregate Ratio Versus Compressive Strength**

## **DISCUSSION**

There are advantages and disadvantages to the various test methods outlined here. When used in conjunction with preconstruction testing, some of these tests help identify batch-to-batch variations resulting from proportioning or mixing. Tests on plastic properties of mortar allow for immediate corrective action. Tests on hardened properties are of less use for mortar quality assurance (during construction) because results are not available until some time later. Visual inspection should not be overlooked as a means of assuring mortar proportioning. Observation of proportioning and mixing procedures can provide “real-time” results on the verification of mortar proportions.

Tests that measure mortar water content or a related property are not to be used for control. Much of the mixing water in fresh mortar will be absorbed by units and workable mortar is necessary to achieve good contact between mortar and unit. Masons will decide on a project by project, day by day, and perhaps even batch by batch basis how much water is needed. Water content is regularly adjusted in the field, and must be, to suit placement conditions. Therefore, cone penetration, consistency retention, and the modified concrete penetrometer test results are not typically useful for quality assurance of mortar. They may be helpful for interpreting the results of other mortar tests or in documenting mortar characteristics in research programs.

Mortar aggregate ratio is sensitive enough to detect differences and can be run quickly. It is a fairly simple test to run, requires no expensive or specialized equipment, is cost effective, and can provide results in time to take corrective action. It can't be used for preblended mortar materials unless the manufacturer provides a sand sample or the correction factor for it. Ruggedness research has identified areas for improvement in the test, and additional work is planned to develop precision and bias data on the method.

Water content has to be run to allow for mortar aggregate ratio calculation. Since its practical usefulness is limited to allow for determination of mortar aggregate ratio, it would seem to make sense to incorporate the water content procedure of ASTM C 780 into the annex for the mortar aggregate ratio test.

Air content measured by C 780 does not correlate well with laboratory tested air content [6] for a number of reasons, including differences in mixing and proportioning procedures and differences in the test methods. Therefore this test has limited applicability for evaluating site-mixed mortar.

Confusion persists about the significance of compressive strength test results for mortar. In fact, C 270 states that it is not to be used to accept or reject mortar. Lab tests are performed according to standard methods for proportioning, mixing and curing. They are a means of determining compliance with ASTM C 270. Field test results are generally lower and more variable than the laboratory tests, and are not expected to meet the property specification requirements. ASTM C 1586 was developed primarily to clarify the appropriate use of and distinction between C 270 (specifications for mortar) and C 780 (quality assurance, testing of mortar).

Very little information is available on the use of the splitting tensile strength test for masonry mortar. What documented and anecdotal information is available would indicate that this test is poorly suited to on-site quality assurance testing.

## **SUMMARY**

The methods outlined here present the common procedures for testing mortar in North America. Available methods can be compared on the merits of accurate, reproducible, and meaningful results, short testing time, portability—or applicability to field performance, and reasonable cost. It is beneficial to compare each test method described here with the others to see which offers the most desirable combination of the following characteristics:

*Meaningful results:* Does the test provide results that directly indicate some aspect of the quality of the mortar? Are there any generally accepted ranges of acceptable and unacceptable values? some baseline value to compare against? Can one use the test result to say yes or no to using the mortar?

*Reproducibility:* Can the test be repeated by the same or another operator to arrive at similar results?

*Sensitivity:* Is the test able to distinguish differences in some aspect of the mortar?

*Portability/ease of use:* Is the test portable (for field use)? Does it require complicated, expensive, or not readily available equipment?

*Speed:* Can the test be performed fast enough to use the results to modify the mortar while the wall is still under construction?

*Expense of testing:* Based on the requirements of making, storing, and testing the samples, is the test cost effective for regular use?

Table 3 looks at the characteristics noted above for each of the test methods described in this paper. A side-by-side comparison of the requirements and test benefits shows that most tests have one or more drawbacks that severely limit their usefulness in assessing mortar quality on construction projects. The best tests remove subjectivity and are able to give reproducible results.

Usually construction has three parameters that control not only how, but also how well it is done: quality, speed, and cost. Often, construction can only optimize one or two of these requirements. If something is to be on a short time schedule, it is likely to be expensive. Or excellent quality might be attainable at a reasonable cost, but it will take longer. Sometimes, a desirable combination of all three criteria (quality, speed, and cost) can be achieved. Such would seem to be the case with the use of mortar aggregate ratio test for quality assurance of mortar.

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**Table 3 – Comparisons of ASTM C 780 Mortar Tests**

<b>Test Method</b>	<b>Meaningful results (for quality assurance)</b>	<b>Reproducibility</b>	<b>Sensitivity</b>	<b>Portability/ ease of use</b>	<b>Speed</b>	<b>Expense of testing</b>
Consistency/ cone penetration	0	+	+	+	+	+
Consistency retention	0	+	+	+	+	+
Modified concrete penetrometer	0	+	+	+	+	+
Mortar aggregate ratio	+	+	+	+	+	+
Air content	-	+	+	+	+	+
Compressive strength	0	+	+	-	-	0
Splitting tensile strength	-	-	0	-	-	-

Key: “+” indicates that test is well suited to the factor being considered, “0” indicates neutral, “-” indicates that the test is less suited to the factor being considered

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